



*The Society for engineering
in agricultural, food, and
biological systems*

An ASAE Meeting Presentation

Paper Number: 051007

Spray deposition and off-target loss in nursery tree crops with conventional nozzle, air induction nozzle and drift retardant

Heping Zhu, Agricultural Engineer, USDA/ARS, ATRU, Wooster, OH, zhu.16@osu.edu

Richard C. Derksen, Agricultural Engineer, USDA/ARS, ATRU, Wooster, OH.

Charles R. Krause, Plant Pathologist, USDA/ARS, ATRU, Wooster, OH.

Ross D. Brazee, Agricultural Engineer, USDA/ARS, ATRU, Wooster, OH.

Randall H. Zondag, Extension Horticulturist, OSU Extension, Lake County, OH.

Robert D. Fox, Agricultural Engineer, USDA/ARS, ATRU, Wooster, OH.

Michael E. Reding, Entomologist, USDA/ARS, ATRU, Wooster, OH.

H. Erdal Ozkan, Professor, FABE, The Ohio State University, Columbus, OH.

**Written for presentation at the
2005 ASAE Annual International Meeting
Sponsored by ASAE
Tampa Convention Center
Tampa, Florida
17 - 20 July 2005**

Mention any other presentations of this paper here, or delete this line.

Abstract. *Spray deposits at various elevations within crabapple trees and on the ground were investigated with an air blast sprayer equipped with conventional hollow cone nozzles, air induction nozzles, and conventional hollow cone nozzles with a drift retardant in a commercial nursery field. Airborne deposits at three elevations on sampling towers and on the ground at several distances from the sprayer were also investigated with the three spray treatments in an open area without trees. Droplet size distributions across spray patterns were measured with a laser particle/droplet image analysis system. In general, there was no significant difference for deposits within nursery tree canopies and on the ground with three different spray techniques. With the 700 L/ha application rate, which was 360 L/ha lower than the rate normally used in nursery application, the tree canopies received over 4 to 14.5 times spray deposits actually needed from the air blast sprayer with the three spray techniques, and a large portion of spray droplets deposited on the ground.*

Keywords. *Spray nozzles, Drift retardant, Air induction nozzles, Airborne, Drift, Nursery crops*

The authors are solely responsible for the content of this technical presentation. The technical presentation does not necessarily reflect the official position of the American Society of Agricultural Engineers (ASAE), and its printing and distribution does not constitute an endorsement of views which may be expressed. Technical presentations are not subject to the formal peer review process by ASAE editorial committees; therefore, they are not to be presented as refereed publications. Citation of this work should state that it is from an ASAE meeting paper. EXAMPLE: Author's Last Name, Initials. 2005. Title of Presentation. ASAE Paper No. 05xxxx. St. Joseph, Mich.: ASAE. For information about securing permission to reprint or reproduce a technical presentation, please contact ASAE at hq@asae.org or 269-429-0300 (2950 Niles Road, St. Joseph, MI 49085-9659 USA).

Introduction

The floral and nursery industries generally produce high-value crops with more complicated strategies of pest control material use and more intensive labor requirements than field crops. Applications of pesticides and other production strategies have ensured adequate and high quality crops to meet the wide variety of canopy structure characteristics, growing circumstance, and marketing requirements. However, many concerns have been raised over the extent of pesticide contamination to the soil, surface water and ground water if excessive amounts of pesticide are used. Pesticide contamination in the environment will potentially threaten the life quality and safety of residents nearby because many nurseries operate in small areas close to residential districts and urban or suburban areas. Consequently, environmentally friendly pesticide application is essential to nursery production.

Although the nursery and horticultural industries are among the fastest growing enterprises in U.S. agriculture, little research has been done to optimize their spray application strategies (Krause et al., 2004). Due to crop similarity, air assisted application technologies for apple and citrus orchards (Fox et al., 1993; Salyani et al., 1987; Doruchowski et al., 1996) are normally adapted to nursery tree crops. However, compared with orchard crops, nursery trees are usually narrow and sharp and are difficult to apply pesticide with conventional delivery systems. Derksen et al. (2004) investigated canopy deposits, spray coverage and downwind ground deposits from an air blast sprayer and an air curtain sprayer in a field with red maple trees, and found adjustments were necessary to sprayer settings used for orchard applications to obtain uniform spray deposits in nursery applications.

Drift retardants were reported to reduce spray drift in many laboratory studies (Yates et al., 1976; Haq et al., 1982; Ozkan et al., 1992; Salyani and Cromwell, 1992; Smith, 1993). Laboratory tests indicated that drift retardants could increase the volume median diameter of spray initially, but most polymer based drift retardants lost effectiveness when recirculated through pumps (Bouse et al., 1988; Reichard et al., 1996; Zhu et al. 1997). Also, considerable time and care is required to mix drift retardants with spray carriers. Although there are some disadvantages with drift retardant additives to spray mixtures, some nursery growers have expressed interest in these chemicals if they can reduce potential drift damages to adjacent crops or contamination of nearby residential areas as found in many laboratory tests.

During the past decade, several types of hydraulic air induction nozzle (also called “low-drift”) were introduced into the market for improving pesticide delivery methods and reducing drift. These nozzles have been reported to have higher volume deposits at lower part of canopies (Zhu et al., 2004) because they could produce greater portion of large droplets than conventional hydraulic nozzles (Koch et al., 2001). Some reports indicated these “low-drift” nozzles did not significantly reduce drift in orchards (Heijne et al., 2002; Landers, 2000). Most air induction nozzles were configured with two small holes on the nozzle chamber upstream from nozzle orifices. Those holes induce air into water flow due to the Venturi effect and reduce pressure at the nozzle orifice.

To obtain the optimum pesticide spray management in nurseries, delivery systems must be operated economically and effectively with minimum canopy disturbance and minimum spray drift. Transport of spray to target plant surfaces with high quality atomization is essential to ensure effective spray application in crop protection. Little information is available on nursery

Mention of proprietary product or company is included for the reader's convenience and does not imply any endorsement or preferential treatment by either USDA/ARS or The Ohio State University.

crop production practices whereby applications of required amounts of pesticides achieve effective pest and disease control with minimum chemical loss. Spray trials with drift retardants or air induction nozzles used for nursery tree applications have not been reported in the literature. Questions remain whether drift retardants and air induction nozzles have potential advantages over conventional nozzles in nurseries, and whether performances similar to air induction nozzles can be achieved with larger conventional hydraulic nozzles with reduced operating pressure.

The objective of this research was to compare spray deposits within tree canopies and off-target loss to the ground and air from an air blast sprayer with conventional hollow cone nozzles, conventional hollow cone nozzle applying a drift retardant spray, and air induction nozzle under nursery field conditions.

Materials and Methods

(1) Foliar spray deposits and ground deposit loss in field 1

Spray deposits within tree canopies and on the ground were evaluated with two trials in field 1 at different times during a growing season. Spray settings for both trials were the same. Field 1 was 200-m long and 30-m wide with seven rows of Spring Snow crabapple trees and five rows of short shrubs. The two species were alternately planted with one row of crabapple trees and one row of shrubs after the first three rows of crabapple trees at the south side of the field. The fourth row of crabapple trees was selected for the spray test. The crabapple trees averaged 2.6-m tall and the average width of trees at 0.9-m above the ground was 1.05 m. Within the first 0.9 m from the ground, there were very few leaves on the stem. Spacing between trees in a row was 1.5 m. The shrubs averaged 1.2 m tall and 1.1 m wide. Except for an open area to the north, field 1 was surrounded by many other plantings with different types of trees.

A model 1500 air blast sprayer (Durand-Wayland, Inc., LaGrange, GA) was used, operated with five identical nozzles equally spaced on one side of the 0.91-m diameter air outlet. The sprayer produced 40 m/s average air velocity near the nozzles. Spray deposits within crabapple tree canopies and on the ground were compared with three different spray treatments: hollow cone nozzles with water only (HC), hollow cone nozzles with water and a drift retardant (HCDR), and air induction nozzles with water only (AI). Nozzles used for HC and HCDR were five conventional hollow cone nozzles (D5-45, Spraying Systems Co., Wheaton, IL) and nozzles used for AI were five flat fan air induction nozzle (AI110-08, Spraying Systems Co., Wheaton, IL). The flow rate from the sprayer was maintained at 24.2 L/min for all three methods. To obtain the 24.2 L/min flow rate, the spray operating pressure was adjusted to 1660 kPa for HC and HCDR and 830 kPa for AI. The sprayer travel speed was 6.4 km/hr at which the application rate was 700 L/ha if both sides of the sprayer were used. As indicated before, only one side of the sprayer was used for the test. The application rate in nurseries normally was 1060 L/ha with the nozzle setting that the capacity of the nozzle at the top of each side of the sprayer was three times the capacity of other individual nozzles as usually recommended for orchard applications.

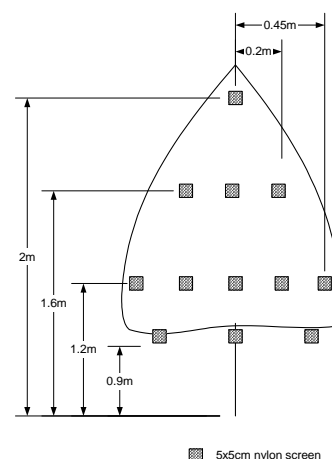


Fig. 1. Location of 12 nylon screens in a crabapple tree to collect foliar spray deposits during trials 1 and 2 in field 1. The screens were perpendicular to the spray direction.

The spray mixture used in two trials was 3 g of Brilliant Sulfaflavine (MP Biomedicals, Inc., Aurora, OH) per liter of water for HC, HCDR and AI. For HCDR, the spray mixture was additionally mixed with STA-PUT™ drift retardant distributed by Helena Chemical Company (Collierville, TN). The drift retardant was liquid formulation with 1% polyvinyl polymer as active ingredient. Concentration of the drift retardant used in the test was 0.49% (v/v).

Ten crabapple trees in the fourth row at the south side of field 1 were randomly selected for sampling in trials 1 and 2. Spray deposits within 10 crabapple tree canopies were collected with 5x5 cm monofilament nylon screens (Filter Fabrics Inc., Goshen, Ind.). Fox et al. (2004) reported the collection efficiency of spray droplets flying in the air from this type of screen ranged 50 to 70% which was much better than flat solid collectors. The screen had a nominal porosity of about 56% or fiber frontal area percentage of 44%. Each tree had 12 screens located in four different elevations (fig. 1) and each screen was hung with a clip attached to a branch of the tree. The screens at the 0.9 m elevation were almost below the tree leaf area. Positions of screens shown in fig. 1 were at the approximately average locations of screens in 10 trees. Screens were placed as close as possible to the tree row centerline.

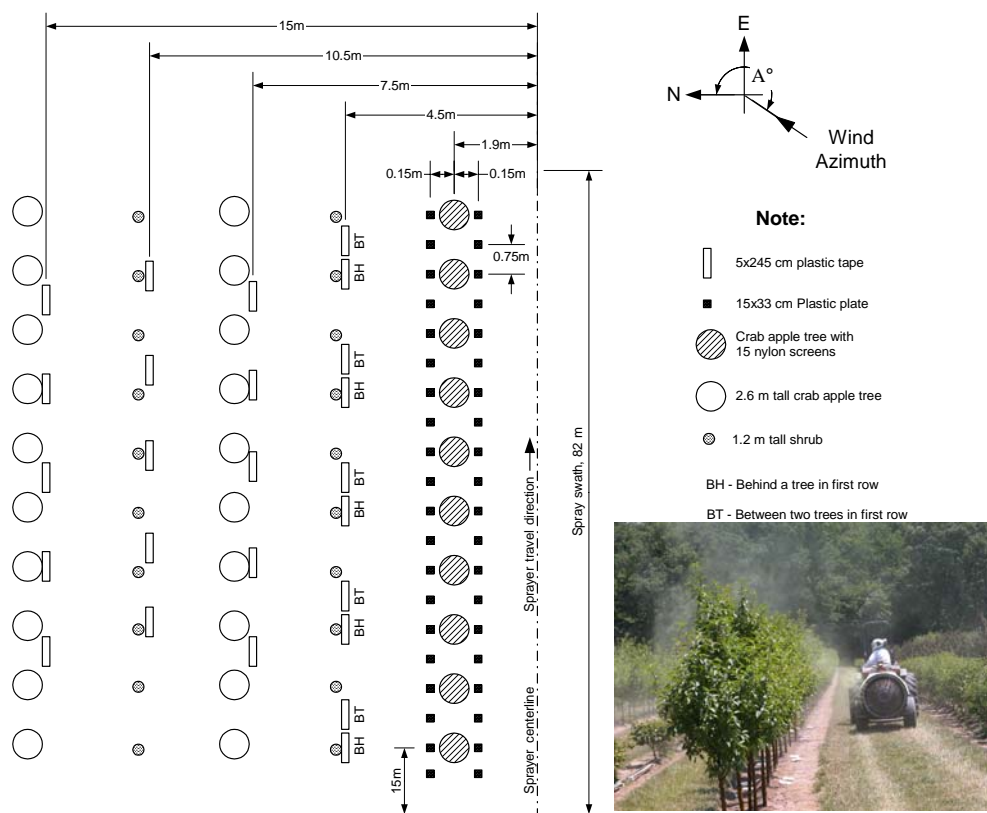


Fig. 2. Plan view of spray site showing location of spray collectors downstream from the air blast sprayer for trials 1 and 2 in field 1.

Spray deposits on the ground beneath trees and in the middle of two trees in the sprayed row were collected with two rows of 15x33 cm plastic plates (fig. 2). The first row of plastic plates was placed 0.15 m in front of the tree centerline and the second row of the plastic plates was 0.15 m behind the tree centerline. Each plastic plate was stabilized on a 15x33 cm wood board with two clips to prevent the plate blowing away by air from the sprayer.

Spray deposits on the ground were collected with 5-cm wide and 245-cm long plastic tapes at four different distances downstream from the sprayer centerline (fig. 2). The distances of the four rows of tapes were 4.5, 7.5, 10.5 and 15.0 m from the sprayer, respectively. Except for the first row of plastic tapes, each row had five plastic tapes placed near the front of trees as shown in figure 2. The first row of plastic tapes was 2.6 m downstream from the first row tree line and was near the front of short shrubs. They were placed in such a way that middle lengths of five tapes were behind the sprayed row trees and middle lengths of other five tapes were placed behind gaps between two sprayed trees. Second-row tapes were placed near the front of the crabapple trees of the same size as the sprayed row trees. Third-row tapes were near the front of the shrubs of the same size as the shrubs near the first row tapes. Fourth-row tapes were near the front of the crabapple trees of the same size as the sprayed row trees.

(2) Airborne and ground deposits in field 2

Airborne spray deposits at three elevations and four distances downwind from the sprayer were determined in field 2, which was about 60 m north of field 1. Field 2 was a 200-m long and 30-m wide open field. This test was originally planned to be part of trials 1 and 2 in field 1. Due to the wind direction suddenly changing before trial 1 started, the airborne deposit measurement was moved to field 2 after trial 1 was completed in field 1. Airborne spray deposits were collected with 20x20 cm nylon screens at elevations of 0.91, 1.83 and 3.05 m and distances of 15, 30, 60, and 90 m downwind from the sprayer. At each of the four distances, three vertical towers of 3.20 m height were used to mount screens at three different elevations. In field 2, spray deposits on the ground were also collected with 5 cm wide and 245 cm long plastic tapes at distances of 7.5, 15 and 30 m from the sprayer while measuring the airborne deposits.

A portable weather station was used to monitor wind velocity and azimuth at one-second interval trials in both fields 1 and 2. Table 1 lists the average wind velocity and azimuth and their coefficients of variation for each trial during the period of sprayer passing the spray swath. The wind changed direction from southwest to northwest after all targets were placed during trial 1. During trial 2, wind direction was southwest when the test was conducted with HC, and then it changed to almost west or northwest for the tests with HCDR and AI. During the airborne deposit test in field 2, wind directions were almost the same but wind velocity varied considerably for HC, HCDR and AI.

Table 1. Wind velocity and azimuth during field tests with hollow cone nozzles (HC), hollow cone nozzle with drift retardant (HCDR), and air induction nozzles (AI) at two trials in field 1 and airborne deposit measurement in field 2. Coefficients of variation that is standard deviation divided by mean were given in parentheses

Test location	HC		HCDR		AI	
	Wind velocity (m/s)	Wind azimuth ^[a] (degree)	Wind velocity (m/s)	Wind azimuth (degree)	Wind velocity (m/s)	Wind azimuth (degree)
Field 1, trial 1	3.1 (17)	316 (6)	2.1 (31)	296 (7)	2.7 (33)	285 (6)
Field 1, trial 2	1.2 (30)	193 (8)	3.4 (25)	272 (9)	2.0 (34)	283 (8)
Field 2	2.3 (41)	308 (7)	1.8 (46)	311 (5)	1.3 (31)	306 (8)

^[a] Wind velocity angle measured clockwise from the north to wind direction.

All field target samples were collected 15 minutes after each spray, and placed in clean glass bottles. Spray deposits on all sampling targets were washed with distilled water after they were brought to the laboratory and then were determined with a Model LS 50B luminescence spectrometer (Perkin-Elmer Limited, Beaconsfield, Buckinghamshire, England) for peak fluorescent intensity analysis.

All field data were analyzed by one way ANOVA, and differences among means were determined with Duncan's New Multiple-Range Test using ProStat version 3.8 (Poly Software International, Inc., Pearl River, NY). All differences were determined at the 0.05 level of significance.

Droplet sizes from nozzles for AI at 830 kPa, and HC and HCDR at 1660 kPa which were similar to wind tunnel test settings were measured with the VisiSizer particle/droplet image analysis system (Oxford Lasers, Oxfordshire, UK). Droplet size distributions were determined at 0.5 m below the nozzle orifice across the spray pattern width with 5 cm interval.

Results and discussion

(1) Foliar deposits in field 1

Except for the screen position at the 0.9 m elevation, there were no significant differences for spray deposits on screens at different elevations within crabapple tree canopies among the three spray techniques with AI, HC and HCDR in both trials (Table 2). Therefore, statistically AI, HC and HCDR produced almost the same quantity of spray deposits within tree canopies. Also,

Table 2. Spray deposits at four elevations within crabapple tree canopies with air induction nozzle (AI), hollow cone nozzle (HC), and hollow cone nozzle with drift retardant (HCDR) for two trials in field 1. Coefficients of variation that is standard deviation divided by mean were given in parentheses

Test	Elevation (m)	Average Spray Deposit ($\mu\text{L}/\text{cm}^2$)		
		AI	HC	HCDR
Trial 1	2.0	2.11 (39) ^a	2.83 (33) ^a	2.23 (46) ^a
Trial 1	1.6	1.61 (65) ^a	2.23 (62) ^a	2.07 (59) ^a
Trial 1	1.2	1.54 (48) ^a	1.74 (53) ^a	1.61 (53) ^a
Trial 1	0.9	1.93 (29) ^b	2.41 (38) ^a	2.29 (28) ^{ab}
Trial 2	2.0	1.94 (33) ^a	1.66 (57) ^a	1.55 (56) ^a
Trial 2	1.6	1.49 (48) ^a	1.50 (64) ^a	1.41 (57) ^a
Trial 2	1.2	1.06 (62) ^a	1.07 (77) ^a	1.39 (64) ^a
Trial 2	0.9	1.23 (39) ^b	1.29 (48) ^b	1.82 (43) ^a

^[a] Means in a row followed by different letters are significantly different ($p < 0.05$).

there were no significant differences among deposits at four elevations within the tree canopy for all three treatments. To produce uniform spray deposits across the tree canopy, air blast sprayers for nursery applications are usually recommended to operate with the same nozzle setting as orchard applications. Specifically, recommendations are to use a large nozzle at the top of each side, with capacity of the top nozzle three times or more than other individual nozzles. However, results in this study with three different spray techniques showed that spray deposit was quite uniform across the tree canopy from top to bottom with the equal capacity nozzles on the air blast sprayer. Nursery trees are usually much thinner, sharper, and less canopy volume per area than orchard trees. It was reasonable to assume from this study that the sprayer with the equal capacity nozzles had the capability to deliver uniform spray deposits throughout the trees.

In trial 1, the average spray deposit on 12 nylon screen collectors within each tree canopy was $1.70 \mu\text{L}/\text{cm}^2$ with 6% coefficient of variations for AI, $2.12 \mu\text{L}/\text{cm}^2$ with 14% coefficient of variations for HC, and $1.95 \mu\text{L}/\text{cm}^2$ with 8% coefficient of variations for HCDR, respectively. In trial 2, the average spray deposit on 12 nylon screen collectors was $1.27 \mu\text{L}/\text{cm}^2$ with 12% coefficient of variations for AI, $1.28 \mu\text{L}/\text{cm}^2$ with 26% coefficient of variations for HC, and $1.50 \mu\text{L}/\text{cm}^2$ with 11% coefficient of variations for HCDR, respectively. Although wind velocities and directions were not the same for the three spray methods, total spray deposits on 12 screens within a tree canopy were not significantly different among sprays with AI, HC and HCDR.

The volume median diameter of water droplets on the main spray sheet from a conventional hollow cone nozzle at 1660 kPa is 202 μm . The volume of $1.28 \mu\text{L}/\text{cm}^2$ spray deposit is

equivalent 296 droplets of 202 μm sustained on a 1-cm² area. The recommended droplet density in the target area was from 20 to 30 droplets per square centimeter for spraying insecticides and 50 to 70 droplets per square centimeter for spraying fungicides (Anonymous, 2004). The number of 202- μm droplets with the 1.28 μL volume within the tree canopy was 4 to 15 times the number of 202- μm droplets actually required for the target area. Therefore, the tree canopies received excessive spray deposits discharged from AI, HC and HCDR at the 700 L/ha application rate.

(2) Ground deposits beneath the sprayed trees in field 1

Table 3. Spray deposits collected by plastic plates on the ground beneath sprayed trees and in the middle of two sprayed trees at locations in front and behind sprayed tree row centerline for AI, HC and HCDR in field 1, respectively. Coefficients of variation that is standard deviation divided by mean were given in parentheses

Trial	Target location related to		Average spray deposit ($\mu\text{L}/\text{cm}^2$)		
	Tree centerline	Trees	AI ^[a]	HC ^[b]	HCDR ^[c]
1	Front	Between	0.23 (65)bB ^[d]	0.56 (40)aB	0.28 (34)bA
1	Front	Beneath	0.24 (41)bB	0.80 (44)aAB	0.33 (44)bA
1	Behind	Between	0.38 (33)bA	0.86 (52)aAB	0.42 (39)bA
1	Behind	Beneath	0.39 (36)bA	1.05 (61)aA	0.41 (46)bA
2	Front	Between	0.58 (44)aA	0.26 (15)bB	0.69 (21)aB
2	Front	Beneath	0.54 (52)aA	0.27 (24)bB	0.77 (19)aB
2	Behind	Between	0.85 (65)abA	0.36 (12)bA	1.00 (30)aA
2	Behind	Beneath	0.91 (57)aA	0.30 (24)bAB	1.22 (17)aA

^[a] AI – Air induction nozzle with water only

^[b] HC – Hollow cone nozzle with water only

^[c] HCDR – Hollow cone nozzle with water and drift retardant

^[d] Means in a row followed by different lowercase letters are significantly different ($p < 0.05$). Means in a column followed by different uppercase letters within the same trial are significantly different ($p < 0.05$).

In general, spray deposits on the ground at 0.15 m in front of the sprayed tree row centerline were significantly less than those at 0.15 m behind the centerline for the plastic plate targets placed beneath trees and between two trees with AI, HC and HCDR in two trials (table 3). This might be because the angled spray pattern delivered more spray droplets to targets behind the centerline than the targets in front of the centerline due to different delivery distances to two locations.

Statistical analysis indicated that there was no significant difference for ground deposits between targets beneath the sprayed trees and in the middle of two sprayed trees for spray methods with AI, HC and HCDR in two trials (table 3). Therefore, compared to the total amount of spray deposits on the ground near the sprayed trees, the amount of spray runoff from tree leaves to the ground was not significantly different among all three treatments. The average spray deposit per square centimeter on the ground beneath the sprayed trees was

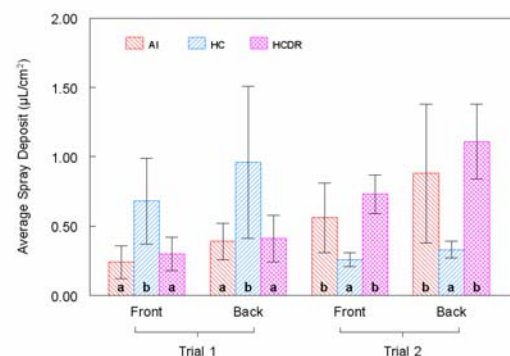


Fig. 3. Average spray deposits collected with plastic plates on the ground at 0.15 m from the front and behind the sprayed tree row centerline for AI, HC and HCDR in field 1, respectively. Bars in a group with different lowercase letters are significantly different ($p < 0.05$)

about 24% of the average foliar deposit per square centimeter within tree canopies with AI, HC and HCDR in two trials.

Ground deposits beneath the sprayed trees with HC were significantly higher in trial 1 but significantly lower in trial 2 than that from AI and HCDR regardless of target placement either in front of trees or behind trees (figure 3). However, for the same conditions, there was no significant difference in deposits between AI and HCDR. This result might have been due to changes in wind velocity and direction for HC in two trials (table 1). Ground targets closer to the air blast sprayer should receive higher spray deposits if the spray direction was against the wind.

(3) Ground deposits downstream from the sprayer in field 1

Data in table 4 illustrates there were no significant differences among spray deposits on the ground at 4.5 m downstream from the sprayer for AI, HC and HCDR in trial 1, but the deposits from HC were significantly lower than those from AI and HCDR in trial 2 due to changes in wind velocities and directions (table 1). There was no significant difference in deposits between the plastic tapes placed behind sprayed trees and gaps of two sprayed trees (figure 4) because there were very few leaves on trees at the first 0.9 m from the ground. The average ground deposit collected by the plastic tapes at 4.5 m from the sprayer with AI, HC and HCDR for the two trials was 1.51, 1.23, and 1.57 $\mu\text{L}/\text{cm}^2$, respectively, which was about 86% of the average spray deposit per square centimeter within tree canopies with AI, HC and HCDR in two trials.

Therefore, a significant amount of spray volume was lost on the ground with all three treatments at the 700 L/ha application rate.

Data in table 4 also illustrate that spray deposits on the ground greatly decreased in different slopes for AI, HC and HCDR as the downstream distance from sprayer increased. At 10.58 m downstream from the sprayer in trial 1, the HCDR produced the highest ground spray deposit among the three spray methods, followed by AI and then HC while wind conditions were 2.7 m/s with 285 degree azimuth ($^{\circ}\text{A}$) for AI, 3.1 m/s

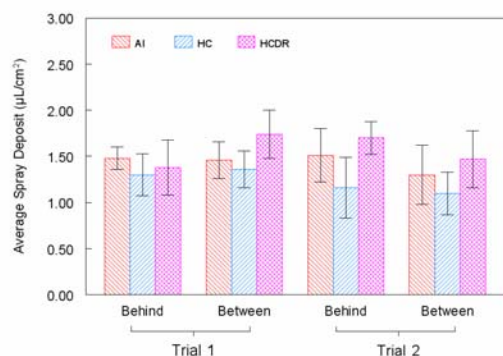


Fig. 4. Ground spray deposits collected with plastic tapes placed behind sprayed trees and between two sprayed trees at 4.5 m downstream from the sprayer for AI, HC and HCDR during two trials in field 1.

Table 4. Average ground spray deposits collected by plastic tapes at different distances downstream from the sprayer with three spray methods for two trials in field 1. Coefficients of variation that is standard deviation divided by mean were given in parentheses

Trial	Distance (m)	Spray deposit ($\mu\text{L}/\text{cm}^2$)		
		AI ^[a]	HC ^[b]	HCDR ^[c]
1	4.45	1.47 (11)a ^[d]	1.33 (15)a	1.56 (21)a
1	7.65	1.06 (10)a	0.40 (58)b	0.96 (27)a
1	10.58	0.38 (46)b	0.00 (215)c	0.57 (19)a
1	14.55	0.00 (176)b	0.00 (31)b	0.10 (66)a
2	4.45	1.42 (22)a	1.13 (24)b	1.58 (17)a
2	7.65	0.54 (66)a	0.48 (8)a	0.58 (35)a
2	10.58	0.39 (22)a	0.26 (16)b	0.11 (38)c
2	14.55	0.08 (94)a	0.02 (46)a	0.02 (58)a

^[a] AI – Air induction nozzle with water only

^[b] HC – Hollow cone nozzle with water only

^[c] HCDR – Hollow cone nozzle with water and drift retardant

^[d] Means in a row followed by different letters are significantly different ($p < 0.05$).

with 316 °A for HC, and 2.1 m/s with 296 °A for HCDR, respectively. At the same places in trial 2, AI produced the highest ground deposit among the three methods, followed by HC and then HCDR while wind conditions were 2.0 m/s with 283 °A for AI, 1.2 m/s with 193 °A for HC, and 3.4 m/s with 272 °A for HCDR, respectively. Obviously, wind conditions had more influence on the ground spray deposits at 10.58 m downwind and beyond than the spray methods.

(4) Airborne and ground deposits in field 2

Screen collectors for 0.91, 1.83 and 3.05 m elevations at 15 m downwind from the sprayer in field 2 collected most airborne deposits from AI, HC and HCDR among the four different downwind sample locations (table 5). There was no significant difference in airborne deposits for the three elevations at both 15 and 30 m downwind from the sprayer between AI and HC methods except for 3.05 m elevation at the 15 m distance although the average airborne deposits with AI were lower than that with HC. However, with the same screen collector locations, HCDR had significantly higher airborne deposits than AI and HC. At 61 and 91 m downwind distances, the airborne spray deposits at the three elevations were very low and not significantly different among the spray methods with AI, HC and HCDR.

In conjunction with the airborne spray deposits, figure 5 shows downwind spray deposits on ground plastic tapes at three distances from the air blast sprayer in field 2 for AI, HC, and HCDR, respectively. At 7.5 m downstream from the sprayer, the downwind spray deposits on the ground were 0.34, 0.68, and 0.92 $\mu\text{L}/\text{cm}^2$ for AI, HC, and HCDR, respectively while they were 0.29, 0.11, and 0.23 $\mu\text{L}/\text{cm}^2$ at 15 m from the sprayer. The downwind spray deposits on the ground at 15 and 30 m from the sprayer with AI were higher than that with HC and HCDR. At 15 m downwind from the sprayer, there were more airborne deposits at all three elevations than ground deposits for HC and HCDR while it was opposite for AI.

Table 5. Average airborne deposits on screens at three elevations and four downwind distances from the sprayer with three spray methods in field 2. Coefficients of variation that is standard deviation divided by mean were given in parentheses

Distance (m)	Elevation (m)	Spray deposit ($\mu\text{L}/\text{cm}^2$)		
		AI ^[a]	HC ^[b]	HCDR ^[c]
15	0.91	0.263 (37)b ^[d]	0.418 (62)b	0.807 (16)a
15	1.83	0.174 (61)b	0.389 (95)ab	0.641 (30)a
15	3.05	0.066 (33)b	0.359 (119)a	0.561 (29)a
30	0.91	0.002 (97)b	0.006 (110)b	0.104 (53)a
30	1.83	0.001 (120)b	0.014 (104)b	0.081 (56)a
30	3.05	0.002 (130)b	0.011 (87)b	0.073 (69)a
61	0.91	0.000 (173)a	0.001 (105)a	0.000 (23)a
61	1.83	0.000 (90)a	0.001 (156)a	0.000 (95)a
61	3.05	0.000 (173)a	0.001 (130)a	0.000 (82)a
91	0.91	0.000 (173)a	0.000 (26)a	0.000 (43)a
91	1.83	0.000 (91)a	0.000 (96)a	0.000 (132)a
91	3.05	0.000 (152)a	0.000 (85)a	0.000 (151)a

^[a] AI – Air induction nozzle with water only

^[b] HC – Hollow cone nozzle with water only

^[c] HCDR – Hollow cone nozzle with water and drift retardant

^[d] Means in a row followed by different letters are significantly different ($p < 0.05$).

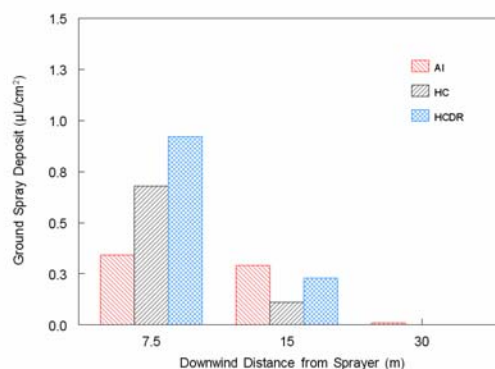


Fig. 5. Downwind spray deposits on the ground at three distances downstream from the air blast sprayer with AI, HC and HCDR in field 2.

Statistical analysis indicated that the wind velocity during the airborne spray test with HC was significantly higher than that with AI and HCDR while difference in wind velocities for treatments between AI and HCDR was not significant. However, the spray mixture with drift retardant in field 2 had the highest airborne spray deposits among the three spray methods. Zhu et al. (1997) reported nonionic polymer drift retardants could lose their effectiveness and performed almost the same as water after 2 to 3 recirculations through a centrifugal pump. The laboratory measurement illustrated that the average $D_{V,1}$, $D_{V,5}$ and $D_{V,9}$ of droplets on the main spray sheet 0.5 m below the nozzle orifice from HCDR were slightly higher than HC, and the $D_{V,5}$ at locations within 10 cm from the nozzle centerline for both HC and HCDR was almost equal and ranged from 30 to 82 μm . Bouse et al. (1988) reported increases in portions of spray volume in both droplet diameter smaller than 99 μm and larger than 415 μm for water soluble polymer drift retardants discharged by conventional hollow cone nozzles in the air flow of 53 m/s.

Likewise, the air induction nozzles did not provide significant drift reduction, compared to using the conventional hollow cone nozzles in field 2. For water droplets, the critical relative velocity at which the droplet will continue to breakup is given by the equation (Lefebvre, 1989),

$$U_R = \frac{784}{\sqrt{D}} \quad (1)$$

where, U_R is the critical relative velocity in m/s and D is droplet diameter in micrometers. For the air blast sprayer, the air velocity near the nozzle is about 40 m/s as indicated above. According to equation (1), any droplets larger than 350 μm in diameter from AI, HCDR and HC would be further breakup by the aerodynamic pressure produced by the parallel air flow from the air blast sprayer. Laboratory droplet size measurement results illustrate that more than 50% of droplets from AI at 830 kPa was larger than 403 μm , and more than 90% of droplets from HC at 1660 kPa was smaller than 290 μm , and more than 90% of droplets from HCDR at 1660 kPa was smaller than 332 μm , respectively. Obviously, a great portion of droplets from AI in the air blast sprayer might have encountered some breakup due to air shearing effect. Therefore, AI and HCDR might not achieve their advantages of producing large droplets as normally claimed to reduce drift potential from the air blast sprayer in the nursery field tests.

Conclusions

1. AI, HC and HCDR produced almost no significantly different quantity of spray deposits within tree canopies. Tree canopies received 4 to 15 times the number of spray droplets as actually needed from HC at the 700 L/ha application rate which was 360 L/ha lower than the rate normally used in nursery application.
2. Spray deposits at different elevations within crabapple trees were not significantly different from the sprayer with five identical nozzles for either AI, HC or HCDR. It was not necessary to place a large capacity nozzle at the top of the air blast sprayer as normally recommended for orchard spray applications.
3. Wind conditions had more influence on the ground spray deposits than the spray method chosen from AI, HC and HCDR in field 1. A large proportion of spray droplets deposited on the ground with all three spray methods with the 700 L/ha application rate.
4. In field 2, although average airborne deposits with AI for elevations of 0.91 and 1.83 m at 15 and 30 m downwind distances from the sprayer were higher than deposits from HC, statistically they were not significantly different. At the same locations, HCDR had significantly higher spray airborne deposits than AI and HC. Downwind spray deposits

on the ground at 15 and 30 m from the sprayer with AI were higher than that with HC and HCDR.

Acknowledgements The authors greatly acknowledge technical assistance by B.A. Anderson, D. Benninger, C.M. Berry, A. Clark, A.A. Doklovic, M.S. Giovannini, H. Guler, L.E. Horst, E. Lu, L.A. Morris, B.E. Nudd, J. Sun, H. Tang, D.T. Troyer, K.A. Williams in preparing setup and collection of large quantity of samples in the field. Cooperation in providing operating facilities, equipment, and experimental field space by R. S. Lyons, owner and R.A. Hart, R.G. Headley and J.F. Daley, Sunleaf Nursery, Madison OH is also gratefully acknowledged.

References

- Anonymous. 2004. A user card containing the recommended droplet density in the target area. Syngenta Crop Protection Ag CH-4002, Basle, Switzerland.
- Bouse, L.F., J.B. Carlton, and P.C. Jank. 1988. Effect of water soluble polymers on spray droplet size. *Transactions of the ASAE* 31(6): 1933-1641, 1648.
- Derksen, R.C., C.R. Krause, R.D. Fox, R.D. Brazee. 2004. Spray delivery to nursery trees by air curtain and axial fan orchard sprayers. *Journal of Environmental Horticulture* 22(1):17-22.
- Doruchowski, G., R. Holownicki, and A. Godyn. 1996. Air jet setting effect on spray deposit within apple tree canopy and loss of spray in orchard. Ag Eng96, The European Conference on Agricultural Engineering, Madrid, Spain. Paper No. 96A-139.
- Fox, R.D., D.L. Reichard, C.R. Krause, R.D. Brazee, S.A. Svensson, and F.R. Hall. 1993. Effect of sprayer type on downwind deposits from spraying orchards. ASAE Paper No. 931078. St. Joseph, Mich.: ASAE.
- Fox, R.D., R.C. Derksen, H. Zhu, R.A. Downer, R.D. Brazee. 2004. Airborne spray collection efficiency of nylon screens. *Applied Engineering in Agriculture* 20(2): 147-152.
- Haq, K., N.B. Akesson and W.E. Yates. 1982. Analysis of droplet spectra and spray recovery as a function of atomizer type and fluid physical properties. In *Pesticide Formulations and Application Systems: 67-82, 3rd Vol.*, ASTM Publication STP 828, Eds. T.M. Kaneko and N.B. Akesson, Philadelphia, Pa.: American Society for Testing and Materials.
- Heijne, B., M. Wennerer, and J.C. Van De Zande. 2002. Air inclusion nozzles don't reduce pollution of surface water during orchard spraying in the Netherlands. *Aspects of Applied Biology* 57, International advances in pesticide application, pp. 193-199.
- Koch, H., H. Knewitz, and G. Fleischer. 2001. Drift reduction and biological efficacy by means of coarse droplet application of pesticides in orchards. *Gesunde Pflanzen* 53: 120-125.
- Krause, C.R., H. Zhu, R.D. Fox, R.D. Brazee, R.C. Derksen, L.E. Horst, and R.H. Zondag. 2004. Detection and Quantification of Nursery Spray Penetration and Off-Target Loss with Electron Beam and Conductivity Analysis. *Transactions of the ASAE* Vol. 47(2): 375-384.
- Landers, A. 2000. Drift reduction in the vineyards of New York and Pennsylvania. *Aspects of Applied Biology* 57, Pesticide Application, pp. 67-73.
- Lefebvre, A.H. 1989. Atomization and Sprays. Hemisphere Publishing Corporation. New York, NY.
- Ozkan, H.E., D.L. Reichard, H. Zhu, and K.D. Akerman. 1992. Effect of drift retardant chemicals on spray drift, droplet size and spray pattern. ASAE Paper No. 92-1613. St. Joseph, Mich.: ASAE.
- Reichard, D.L., H. Zhu, R.D. Fox and R.D. Brazee. 1992. Wind tunnel evaluation of a computer program to model spray drift. *Transactions of the ASAE* 35(3): 755-758.
- Reichard, D.L., H. Zhu, R.A. Downer, R.D. Fox, R.D. Brazee and H.E. Ozkan. 1996. A laboratory system to evaluate effects of shear on spray drift retardants. *Transactions of the*

- ASAE 39(6): 1993-1999.
- Salyani, M., and R.P. Cromwell. 1992. Adjuvants to reduce drift from handgun spray applications. In *Pesticide Formulations and Application Systems: 363-376, 12th Vol.*, ASTM Publication STP 1146, Eds. B.N. Devisetty, D.G. Chasin and P.D. Berger, Philadelphia, Pa.: American Society for Testing and Materials.
- Salyani, M., S.L. Hedden, and G.J. Edwards. 1987. Deposition efficiency of different droplet sizes for citrus spraying. *Transactions of the ASAE* 30(6): 1595-1599.
- Smith, A. 1993. Adjuvants in crop protection. Grow Bus. Report DS 86. New York, N.Y.: PharmaBooks Ltd.
- Yates, W.E., N.B. Akesson and David Bayer. 1976. Effects of spray adjuvants on drift hazards. *Transactions of the ASAE*, Vol.19, No.1, pp. 41-46.
- Zhu, H., R.W. Dexter, R.D. Fox, D.L. Reichard, R.D. Brazee and H.E. Ozkan. 1997. Effects of polymer composition and viscosity on droplet size of recirculated spray solutions. *Journal of Agricultural Engineering Research* 67: 35-45.
- Zhu, H., J.W. Dörner, D. L. Rowland, R.C. Derksen, and H. E. Ozkan. 2004. Spray penetration into peanut canopies with hydraulic nozzle tips. *Biosystems Engineering* 87(3): 275-283.